1952

# An economic study of the "C" factor

David Hunter Robinson

AN ECONOMIC STUDY OF

THE "C" FACTOR

BY

DAVID HUNTER ROBINSON

---------------

A

THESIS

submitted to the faculty of the

SCHOOL OF MINES AND METALLURGY OF THE UNIVERSITY OF MISSOURI

in partial fulfillment of the work required for the

Degree of

MASTER OF SCIENCE IN CIVIL ENGINEERING

Rolla, Missouri

1952

------



Approved by E. W. Carlton
Professor of Structural Engineering

ACKNOWLEDGMENTS

I wish to express my deep appreciation to Mr. Daniel Dennedy, region Engineer, U. S. Geological Survey, for his cooperation, guidance, and interest in making this thesis possible.

I am deeply grateful, also, to Professor E. W. Carlton for his encouragement and excellent advice.

To Mr. Noel Hubbard I am indebted for his unselfish interest and advice contributory to the completion of this thesis. His Christian attitude toward those who need assistance has been an inspiration to me in my work.

The cooperation of the staff of the Central Region of the U. S. Geological Survey was invaluable. Special appreciation is expressed to Mr. M. J. Harden, Mr. W. R. Broaddus, and Mr. A. C. McCutchen for their time, advice, and use of facilities and equipment; to Mr. J. M. Lawson and Mr. E.J. Kimmick for their aid in field work; to Mr. Elmer Kee and Mr. H. E. Doerr for their help with photographic work; to Mr. R. A. Schwab for his aid in reproducing illustrations.

I appreciate the generosity of Mr. Farney and other property owners for permission to use their property for the test area.

I am indebted to the following for their informative letters:

Mr. A. O. Quinn
Aero Service Corporation

Mr. Leon T. Eliel
Fairchild Aerial Surveys, Inc.

Bausch & Lomb Optical Co.

Abrams Aerial Survey Corp.

Jack Ammann
Photogrammetric Engineers

Zeiss Aerotopograph
Munich, Germany

Also very much appreciated was the time devoted by Mr. Robert A. Shoolbred to the progress of the field work.

To my wife, whose encouragement, loyalty, and help in the preparation of the manuscript merits my undying love and appreciation.

# TABLE OF CONTENTS

# LIST OF ILLUSTRATIONS

CONTOUR TEST AREA
White Dots Represent Flight Markers of Paper at Known Elevations

# INTRODUCTION

The "C" factor has long been a much discussed problem among engineers concerned with aerial mapping. It is a problem that directly affects the economy of every mapping job where aerial photographs form the basis of the topographic interpretation.

First, it will be necessary to discuss, at length, just what is meant by the term "C" factor. What does it include and upon what does it depend? Of what good is it and how variable is it?

It is a term used in aerial mapping to indicate the ratio of the flight height to the contour interval. A "C" factor of 800 means that the flight altitude was 800 times the contour interval. If the intended contour interval were 10 feet, then the flight altitude must be 8000 feet above mean ground. If the intended contour interval were 5 feet, then the flight altitude must be 4000 feet above mean ground.

Now comes the question of how it may be used in actual practice. Suppose it is desired to map an area using a 10 foot vertical interval between contours. What "C" factor should be used? The planning engineer must examine the terrain involved and arrive at an answer. His answer will depend, not upon a set of tables, or a formula from a text book, but upon his judgment.

He will consider whether the slopes are steep or flat, whether the area is predominantly wooded or clear, the accessibility of the area to ground survey parties, the type of photogrammetric plotting instruments to be used, and many possible items, but most of all he should consider the required standard of accuracy of the finished product. If several engineers were asked to form opinions independently, there would probably be several different answers depending upon the experience of each. As an example of this difference of opinion, the Eastern region of the United States Geological Survey commonly used a "C" factor of 600 in its multiplex mapping of areas where 10 foot contours are used; whereas, the Central region commonly uses a "C" factor of 850 on similar areas.

What are the advantages of using a high or a low "C" factor? The answer to this question is a matter of economy. All aerial mapping requires a certain amount of ground surveying. The amount of ground surveying required depends largely upon the number of aerial photographs taken. A higher flight altitude requires fewer pictures and, therefore, less ground surveying, less photo-processing of negatives, less office work in the planning of survey work, fewer models to work in the plotting instruments, to mention a few of the processes.

Immediately, the question arises--why not use a "C" factor of 2000? In this case, the answer is that the higher the flight altitude the more difficult it becomes to maintain a prescribed standard of accuracy throughout the photogrammetric stages, the most critical stage being the stereo-plotting.

It is a problem that involves a number of complex variables for which no definite value can reasonably be established. For example, some of the variables affecting the accuracy of a multiplex diapositive are as follows:

(1) the quality of glass of which the diapositive is made

(2) the quality of the emulsion

(3) the degree of adhesion between the emulsion and the glass (sometimes the emulsion is said to slip)

(4) the accuracy of the diapositive printer

(5) the temperature, quality and speed of the developer

(6) the ability and conscientiousness of the photographer responsible for the processing

The term itself may be used rather loosely in its meaning. For the purpose of this study, however, the evaluation of the finished stereo compilation will form the basis for such conclusions as may be reached. Careful reshaping of contours to eliminate the obvious irregularities inherent in the use of the tracing table is considered to result in improved accuracy and, therefore, has been incorporated as a part of this test. The practice of "respacing" contours has been eliminated as being a possible source of error not to be tolerated in an investigation of this kind, though some wooded area is included.

From the preceeding discussion, it is clear that no really definite "C" factor can be ascribed to any plotting instrument and be considered as dependent upon the quality of the instrument only. Also, it is conceivable that a situation may arise whereby a 10 foot vertical interval between contours may be specified, and at the same time, specifying that the accuracy required, instead of the customary ± half contour interval, shall be ± two feet. This would require a "C" factor normally applicable to 4 foot contours and a flight altitude of possibly 3000 feet, thereby indicating a "C" factor of 300 for this hypothetical case.

In like manner, a comparable condition exists when the compilation is really more accurate than the specifications require, making possible the use of a higher "C" factor than was actually used. For example, suppose an area were flown at an altitude of 5000 feet and the specified contour interval were 10 feet. After the compilation is completed, it is found by field test that the contours are accurate within ± 3 feet, whereas the specifications require only ± a half contour interval or 5 feet. This would indicate that a "C" factor of 650 or possibly 700 could have been used, thereby effecting greater economy in the making of the map.

## PURPOSE OF RESEARCH

After due consideration of the facts and hypothetical conditions enumerated herein, it was decided that this work would be devoted to developing a means of determining the most economical "C" factor to be used; one that will be consistent with ease of operating the plotting machine, the required accuracy of the finished compilation and economy. In other words, the highest value of the "C" factor that will produce results within the accuracy requirements under normal operating procedures.

As a secondary project, it was decided to plot a curve using points determined by analyzing a series of spot readings made at each altitude tested. In well flattened models, this test should provide a well graduated series of points such that the resultant curve might be considered as an accuracy rating or "C" factor curve ascribable to the plotting instrument itself, the human element being practically a constant.

It is not expected that this thesis will present a complete and fool-proof answer to the problem. It is hoped, however, that a method of approach leading to a reasonable solution will be presented that will make a start in the right direction and justify additional research that will finally divulge an answer satisfactory to all concerned.

# METHOD OF APPROACH

It is theoretically possible to use one of any number of "C" factors with any mapping job. However, as has been enumerated previously, the reason for not using a smaller ratio than necessary is a matter of economy. The upper limit of the ratio must be that value beyond which the required accuracy of the stereo compilation will be compromised. Therefore, since the greatest economy is achieved when the upper limit of the "C" factor is used, the problem is resolved into a matter of determining those upper limits. If a definite value could be determined for the vertical error normally to be expected to occur in using photographs taken at some known altitude, then by taking photographs of the same area from several different altitudes a limit of the accuracy of each altitude could be determined.

By plotting the errors as the abscissa versus the flight altitude as the ordinate, the resultant curve should be one such that for any given accuracy requirements the maximum or most economical flight height could readily be determined. Then, with the desired contour interval known, the most economical "C" factor may be derived if desired.

The investigator in attempting to establish such a curve, has kept in mind throughout the investigation that different operators will achieve different results. Also, it was realized that different machines of the same general type will produce a variety of results, though the variation would, in this case, be so small as to be negligible when compared with the operator results. To be in keeping with good mapping practice and in order that the human error should be as nearly a constant as possible, the process of parallaxing, scaling and flattening was performed as accurately as possible.

## THE USE OF FLIGHT MARKERS

In an effort to improve the reliability of the test results, the usual means of checking a contoured area by the profile method was discarded as being less accurate than desired.

In order that a higher degree of accuracy would be achieved, a series of markers were placed in a representative area along the general direction of a contour. These markers must needs be visible on the photographs and the elevation of each must be known. They could not be placed directly on a contour, however, because this would create a strong tendency for the operator to merely trace through the points as seen on the projected model.

## PREPARING THE TEST AREA

An area about 3000 feet long was selected, partly in the woods and partly in the open, on slopes varying from moderate to steep (from 5% to 18% approximately). Sixty points were surveyed on this area with a dumpy level. Twenty were placed throughout the length of the area at elevation 942.8. The other forty points were placed above and below this elevation, the variation in elevation being from one foot above and below to nine feet above and below. The thought behind this procedure was not only to discourage the operator from tracing the contour through the points, but, also, to provide sufficient vertical space for the placing of more than one contour through the test area at each altitude. In this way it was possible to utilize more check points in close proximity to a contour rather than make long measurements with a corresponding increase in the difficulty of determining the proper ground position in the field. (See Measuring H Distance).

In order that a better scaling and flattening solution might be obtained for the large scale models, markers were placed in other advantageous positions (See Control Surveys). This eliminated the necessity of depending upon fence corners, road intersections and like identifiable objects. An examination of the 1940 foot altitude photographs will show that there are very few good natural points for either horizontal or vertical control to be found in such a small area.

The markers used were paper weighted with rocks. They varied in size from about 20 to 36 square feet. The smaller ones were in the form of a solid rectangle whereas some of the larger ones were in the form of a box, while others were in the form of a cross as shown.

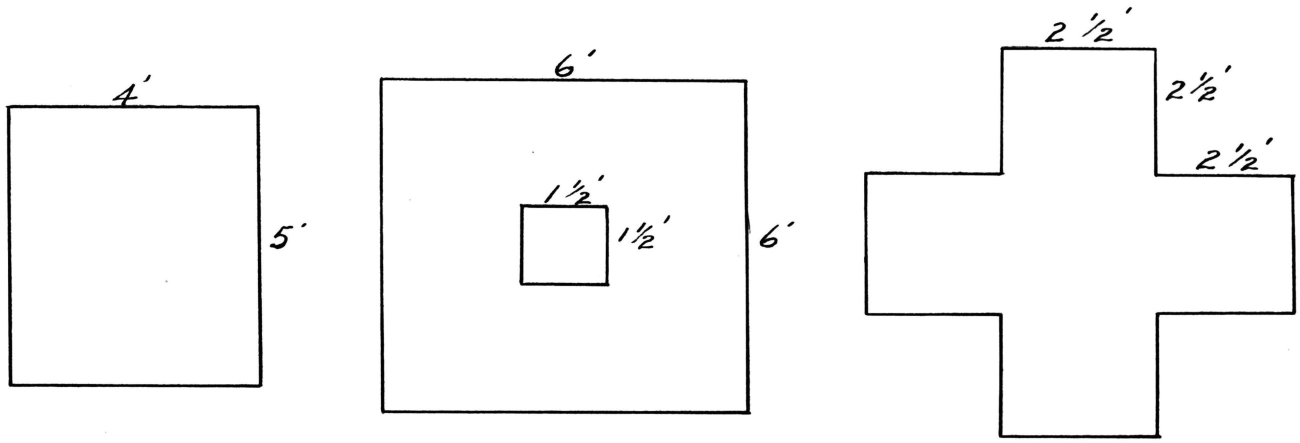



Figure No. 1
Various Shapes and Sizes of Markers Used

Of the three shapes, the solid rectangle seemed to give the best results. Above six thousand feet none of the markers retained their identity. They became merely white dots, though they were still clearly visible on photographs taken at twenty thousand feet. (The ability of an object to create a reaction on the emulsion at a high altitude is a function of the amount of light reflected toward the camera and not of its size. See more detailed explanation in discussion of results).

CONTROL SURVEYS

Twenty-three flight markers, in addition to those used in the contour test area, were placed in order to facilitate the scaling and flattening of the lower altitude models. The position and elevation of each and the elevation of additional identifiable points were established by transit traverse and leveling using third order methods. (Figure 2). The transit traverse lines closed within four feet which was well within the required accuracy, while the level lines closed to within two tenths of a foot, also, well within the required accuracy. However the leveling errors were distributed, nonetheless.

The elevation of the contour area markers was established to the nearest tenth of a foot.

Figure 2
Control Distribution

## THE AERIAL PHOTOGRAPHS

The aerial photographs were flown by Aero-Exploration of Tulsa, Oklahoma. A modified Fairchile K-17 camera with a six inch Bausch and Lomb Metrogon lens was used (Figure 3). The camera was mounted in a P-38 Plane. The shutter speed was set at 1/200 of a second throughout all the flights, with the plane slowed to approximately 150 miles per hour for the lowest altitude. The weather conditions were excellent, and the pictures were taken between 10:20 and 11:30 a.m., April 29, 1952. (Figure 4). The leaves were beginning to come out, but were not far enough advanced to more than add a sense of reality to the problem of contouring through the wooded areas.

## THE BASE SHEET PREPARATION

The scale of the photographs at mean ground level were determined as closely as possible by comparison with an existing U. S. Geological Survey 1/24,000 scale map. (Figure 5). The altitudes as reported by the cameraman were revised to fit the photo scale in order that the scale of the base sheet projectors would be such as to orient the multiplex projectors as nearly to their optimum projection distances as would be consistent with good planning.

Metal mounted paper was used in the preparation of the base sheets. Though the area was small, the horizontal

Figure 3. Lens Calibration Report.

Form 259
16—41016-1

UNITED STATES DEPARTMENT OF COMMERCE
WASHINGTON

# National Bureau of Standards

IV-4/Tp-112008

# REPORT

on
ONE PHOTOGRAPHIC OBJECTIVE
mounted in
Fairchild Aerial Camera No. AC41-321
Submitted by
Aero Exploration Company,
4120 South Peoria,
Tulsa, Oklahoma.

on
January 16, 1947

| | |
|---|---|
| Equivalent focal length | 153.56 mm |
| Calibrated focal length | 153.56 mm |

The probable errors of these determinations of focal length do not exceed ±0.10 mm.

| Lens | DISTORTION | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | 5° | 10° | 15° | 20° | 25° | 30° | 35° | 40° | 45° |
| | 0.00 | 0.00 | +0.01 | +0.04 | +0.05 | +0.08 | +0.11 | +0.06 | -0.12 |

The values of the distortion are measured in millimeters and indicate the displacement of the image from its distortion-free position. A positive value indicates a displacement from the center of the plate. The probable error is approximately ±0.02 mm.

| Lens | RESOLVING POWER | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 0° | 5° | 10° | 15° | 20° | 25° | 30° | 35° | 40° | 45° |
| Tangential | 27 | 38 | 38 | 38 | 27 | 27 | 27 | 38 | 27 | 19 |
| Radial | 27 | 27 | 38 | 38 | 38 | 38 | 38 | 38 | 38 | 27 |

Figure 3. Lens Calibration Report.

* 2 *

The values of the resolving power are given at 5° intervals from the center of the field and are obtained by photographing suitable test charts comprised of patterns of parallel lines. The series of patterns of the test chart are imaged on the negative with the lines spaced 4.8, 7,10,14,19, 27,38,55, and 77 lines to the millimeter. The row marked "Tangential" gives the number of lines per millimeter in the image on the negative of the finest pattern of the test chart that is distinctly resolved into separate lines when the lines lie perpendicular to the radius drawn from the center of the field. The row marked "radial" gives similar values for the pattern of test lines lying parallel to the radius.

All measurements were made with parallel light incident on the lens. The effective wave length was approximately 575 millimicrons.

The attached sketch shows the location of the principal point with respect to the intersection of lines joining opposite pairs of collimation index markers. The probable error of this determination does not exceed ±0.03 mm.

This is a Bausch and Lomb Metrogon lens, nominal focal length 6 inches, maximum aperture f/6.3. The lens bears no serial number; it is mounted in a Fairchild shutter whose serial number is 42-2782. It was tested at maximum aperture while mounted in Fairchild camera No. AC41-321 equipped with magazine No. 41-1950 which is bolted to the camera. The surface of the platen against which the film is held to insure its planeness does not depart more than ±0.0005 inch from a plane.

For the Director,
by

Irvine C. Gardner
Irvine C. Gardner,
Chief, Optical Instruments Section,
Division of Optics.

NBS Test No. Tp-112008,
Washington, D. C.,
13 February 1947.

Figure 4. Photographer's Report

| FLIGHT NUMBER | ALTIMETER | AIR CONDITION | HAZE | TEMPERATURE | ESTIMATED GROUND SPEED | CAMERA SPEED | DIAPHRAGM SETTING | REMARKS |
|---|---|---|---|---|---|---|---|---|
| 1 | 2800 | rough | light | 23 deg. c | 150 mph | 225 | F-14 | Exp. 6 thru 12<br>71 thru 78<br>drift 6 deg. R |
| 2 | 4710 | rough | light | 18 deg. c | 150 mph | 225 | F-14 | Exp. 13 thru 18<br>66 thru 70<br>drift 6 deg. R |
| 3 | 6600 | smooth | medium | 15 deg. c | 180 mph | 225 | F-14 | Exp. 37 thru 40<br>drift 4 deg. R |
| 4 | 9000 | smooth | medium | 9 deg. c | 180 mph | 225 | F-14 | Exp. 41 thru 46<br>drift 2 deg. R |
| 5 | 12380 | smooth | medium | 1 deg. c | 250 mph | 225 | F-14 | drift 2 deg. R |
| 6 | 15180 | smooth | heavy | 3 deg. c | 250 mph | 225 | F-14 | Exp. 53 thru 57<br>drift 2 deg. R |

control was plotted by use of geographic coordinates. (Figure 5)

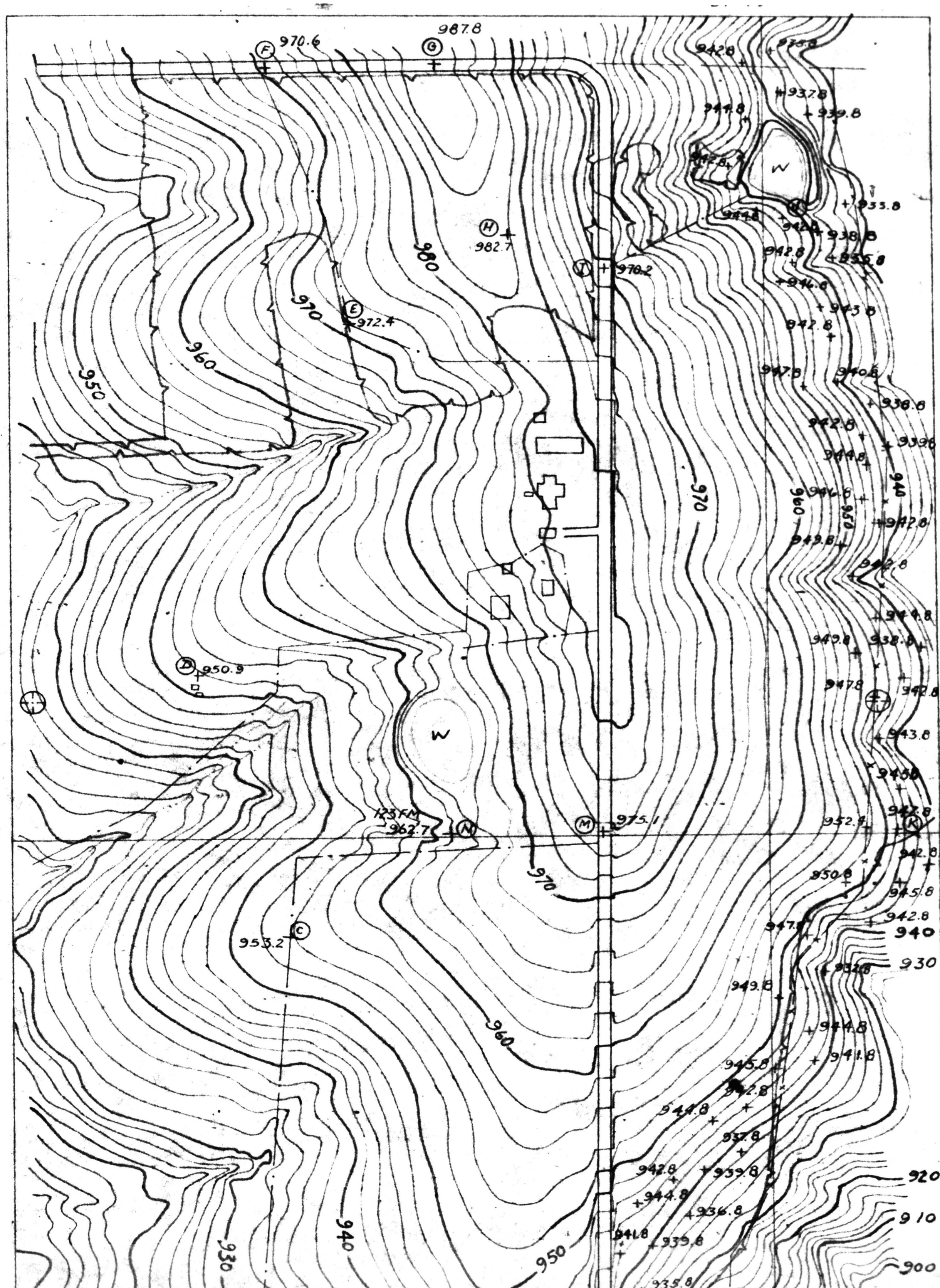
## MAKING THE DIAPOSITIVES

The negatives were somewhat underdeveloped and, therefore, special care was needed in order to bring out the detail and accentuate the contrast to the best advantage. Excellent results were achieved by using a split developer that is designed to produce clearer detail than can be obtained by use of normal developers.

Figure 5

| Flight No. | Stated Altitude Above Mean Ground | Altitude by Scale Check: Check #1 | Check #2 | Check #3 | Average | * Altitude Above Sea level | Photo Scale | Plotting Scale |
|---|---|---|---|---|---|---|---|---|
| 1 | 1840 | 1940 | 1962 | 1919 | 1940 | 2900 | 1/3850<br>1"=321' | 1/1680<br>1"=140' |
| 2 | 3750 | 4186 | 4120 | 4209 | 4170 | 5130 | 1/8277<br>1"=690' | 1/3600<br>1"=300' |
| 3 | 5640 | 6030 | 6086 | 6125 | 6080 | 7040 | 1/12,068<br>1"=1006' | 1/5160<br>1"=430' |
| 4 | 8040 | 8561 | 8564 | 8625 | 8580 | 9540 | 1/17,030<br>1"=1419' | 1/7320<br>1"=610' |
| 5 | 11,420 | 12,269 | 12,003 | 12,038 | 12,100 | 13,060 | 1/24,017<br>1"=2001' | 1/10,000<br>1"=833' |
| 6 | 14,220 | 14,854 | 14,711 | 14,882 | 14,820 | 15,780 | 1/29,416<br>1"=2451' | 1/12690<br>1"=1050' |
| 7 | 19,065 | 19,659 | 19,708 | 19,958 | 19,800 | 20,760 | 1/39,301<br>1"=3275' | 1/16,800<br>1"=1400' |

* Mean elevation of Test Area = 960 feet above Sea level




1/1680 Scale model with 2ft. contours, reduced Photographically to scale of 1/2180.

Map of Test Area

## THE MULTIPLEX TEST

Description of equipment. A multiplex operator tatally unfamiliar with the flight markers and other control was utilized in this phase of the work. Bausch and Lomb projectors mounted on a short frame with an adjustable slate table top were used with a tracing table equipped with a Veeder Root counter.

Spot reading tests. The process of parallaxing, scaling and flattening the models was carried out carefully in order to assure consistent results. Although an abundance of vertical control had been obtained, only one point near each corner of the neat model and one or two near the center were used.

In making the series of spot readings for each altitude the points to be used were selected with care. Every effort was made to see that the points were representative of the entire area of the model and that they were good readable points and not misleading. The spot readings, with the operator in ignorance of what the readings should be, in addition to being recognized as yielding the best results of which the plotting machine is capable with the human element included, also provides, on well distributed positions, a reliable indication of the character of the entire model.

In these tests the points to be read were spotted on the projection for the operator who then called out his readings to be recorded. The operator was kept in ignorance of the correct readings until after the test was completed. No attempt was made to use the same points each time because each change of altitude increased the area covered by the model and, therefore, brought new points into play. However, some of them were used several times at different scales.

These readings are given below so that the reader may evaluate them from a different point of view if he so desires. The resultant, curve will be discussed later under conclusions.

# SPOT READINGS

## Flight 1
Correct Readings in Parenthesis

| | | | |
|---|---|---|---|
| (1)(23.10) | (2) (27.79) | (3)(27.39) | (4)(31.27 |
| 23.05 | 27.78 | 27.35 | 31.20 |
| 23.03 | 27.75 | 27.35 | 31.20 |
| 23.05 | 27.78 | 27.35 | 31.25 |
| Ave.=23.04 | Ave.=27.77 | Ave.=27.35 | Ave.=31.22 |
| -.06 | -.02 | -.04 | -.05 |

| | | | |
|---|---|---|---|
| (5)(30.95) | (6)(34.08) | (7)(33.15) | (8)(30.88 |
| 30.95 | 34.10 | 33.18 | 30.95 |
| 31.00 | 34.05 | 33.15 | 30.95 |
| 30.95 | 34.08 | 33.15 | 30.95 |
| | | 33.18 | |
| Ave.=30.97 | Ave.=34.08 | Ave.=34.17 | Ave.=30.95 |
| +.02 | 0 | +.02 | +.07 |

| | | | |
|---|---|---|---|
| (9)(26.81) | (10)(25.93) | (11)(31.77) | (12)(29.52) |
| 26.86 | 25.90 | 31.73 | 29.40 |
| 26.88 | 25.90 | 31.73 | 29.45 |
| 26.90 | 25.88 | 31.75 | 29.45 |
| Ave.=26.86 | Ave.=25.89 | Ave.=31.74 | Ave.=29.43 |
| +.05 | -.04 | -.03 | -.09 |

Maximum error .09mm=.496 feet

Ave. error=.041mm=.23 feet

## FLIGHT 2

| | | | |
|---|---|---|---|
| (1)(79.57) | (2)(81.50) | (3)(83.63) | (4)(76.95) |
| 79.58 | 81.52 | 83.65 | 77.10 |
| 79.55 | 81.45 | 83.58 | 77.05 |
| 79.55 | 81.50 | 83.60 | 77.08 |
| ve.=79.56 | Ave.=81.49 | Ave.=83.61 | Ave.=77.08 |
| -.01 | -.01 | -.02 | +.13 |

FLIGHT 2(cont.) SPOT READINGS (cont.)

| (5)(85.08) | (6)(80.00) | (7)(78.88) | (8)(74.59) |
|---|---|---|---|
| 84.96 | 80.16 | 78.94 | 74.68 |
| 85.08 | 80.12 | 78.90 | 74.65 |
| 85.08 | 80.10 | 78.90 | 74.65 |
| Ave.=85.04 | Ave.=80.13 | Ave.=78.91 | Ave.=74.66 |
| -.04 | +.13 | +.03 | +.07 |

| (9)(75.46) | (10)(80.25) | (11)(79.86) |
|---|---|---|
| 75.65 | 80.38 | 80.00 |
| 75.57 | 80.35 | 79.95 |
| 75.55 | 80.35 | 79.98 |
| Ave.=75.59 | Ave.=80.36 | Ave.=79.98 |
| +.13 | +.11 | +.12 |

Maximum error = .13mm = 1.53 ft.
Ave. error= .07mm = .83 ft.

FLIGHT 3

| (1)(54.78) | (2)(57.33) | (3)( 59.22) | (4)(63.49) |
|---|---|---|---|
| 54.57 | 57.10 | 59.00 | 63.25 |
| 54.50 | 57.18 | 59.00 | 63.30 |
| 54.50 | 57.15 | 59.00 | 63.30 |
| Ave.=54.52 | Ave.=57.14 | Ave.=59.00 | Ave.=63.32 |
| -.26 | -.19 | -.22 | -.17 |

| (5)(59.46) | (6)(59.61) | (7)(57.08) | (8)(54.86) |
|---|---|---|---|
| 59.30 | 59.45 | 56.90 | 54.85 |
| 59.35 | 59.45 | 56.85 | 54.90 |
| 59.30 | 59.40 | 56.90 | 54.88 |
| Ave.=59.32 | Ave.=59.43 | Ave.=56.88 | Ave.=54.88 |
| -.14 | -.18 | -.20 | +.02 |

SPOT READINGS (cont.)

FLIGHT 3 (cont.)

| | | |
|---|---|---|
| (9)(52.65) | (10)(53.69) | (11)(59.80) |
| 52.58 | 53.55 | 59.70 |
| 52.58 | 53.50 | 59.65 |
| 52.58 | 53.50 | 59.65 |
| Ave.=52.58 | Ave.=53.52 | Ave.=59.67 |
| -.07 | -.17 | -.13 |

Maximum error = .26mm = 4.40 ft.
Ave. error = .16mm = 2.71 ft.

FLIGHT 4

| | | | |
|---|---|---|---|
| (1)(38.81) | (2)(37.50) | (3)(39.13) | (4)(40.08) |
| 38.93 | 37.50 | 39.05 | 40.05 |
| 38.95 | 37.45 | 39.02 | 39.98 |
| 38.95 | 37.48 | 39.05 | 40.02 |
| Ave.=38.94 | Ave.=37.48 | Ave.=39.04 | Ave.=40.02 |
| +.13 | -.02 | -.09 | -.06 |

| | | | |
|---|---|---|---|
| (5)(41.13) | (6)(43.58) | (7)(41.84) | (8)(41.91) |
| 41.15 | 43.70 | 41.95 | 41.95 |
| 41.15 | 43.65 | 41.85 | 41.92 |
| 41.19 | 43.67 | 41.85 | 41.95 |
| Ave.=41.16 | Ave.=43.67 | Ave.=41.88 | Ave.=41.93 |
| +.13 | +.09 | +.04 | +.02 |

| | | | |
|---|---|---|---|
| (9)(45.38) | (10)(37.46) | (11)(38.80) | (12)(41.02) |
| 45.42 | 37.45 | 38.85 | 41.02 |
| 45.35 | 37.48 | 38.75 | 41.05 |
| 45.38 | 37.45 | 38.82 | 41.02 |
| Ave.=45.38 | Ave.=37.46 | Ave.=38.81 | Ave.=41.03 |
| 0 | 0 | +.01 | +.01 |

Maximum error = .13mm = 3.12 ft.
Ave. error = .0508mm = 1.22 ft.

SPOT READINGS (cont.)

FLIGHT 5

| | | | |
|---|---|---|---|
| (1)(28.41) | (2)(27.45) | (3)(28.27) | (4)(30.11) |
| 28.35 | 27.50 | 28.22 | 30.25 |
| 28.25 | 27.45 | 28.18 | 30.18 |
| 28.28 | 27.45 | 28.20 | 30.20 |
| Ave.=28.29 | Ave.=27.47 | Ave.=28.20 | Ave.=30.21 |
| -.12 | +.02 | -.07 | +.10 |

| | | | |
|---|---|---|---|
| (5)(30.45) | (6)(31.90) | (7)(30.68) | (8)(30.86)wooded |
| 30.58 | 32.03 | 30.68 | 30.68 |
| 30.58 | 31.96 | 30.68 | 30.68 |
| 30.59 | 31.99 | 30.66 | 30.70 |
| Ave.=30.58 | Ave.=31.99 | Ave.=30.67 | Ave.=30.69 |
| +.13 | +.09 | -.01 | -.17 |

| | | | |
|---|---|---|---|
| (9)(30.03) | (10)(27.42) | (11)(28.63) | (12)(26.85 |
| 30.08 | 27.38 | 28.60 | 26.88 |
| 30.00 | 27.32 | 28.58 | 26.87 |
| 30.06 | 27.38 | 28.63 | 26.88 |
| Ave.=30.05 | Ave.=27.36 | Ave.=28.60 | Ave.=26.88 |
| +.02 | -.06 | -.03 | +.05 |

Maximum error = .17mm = 5.58 feet

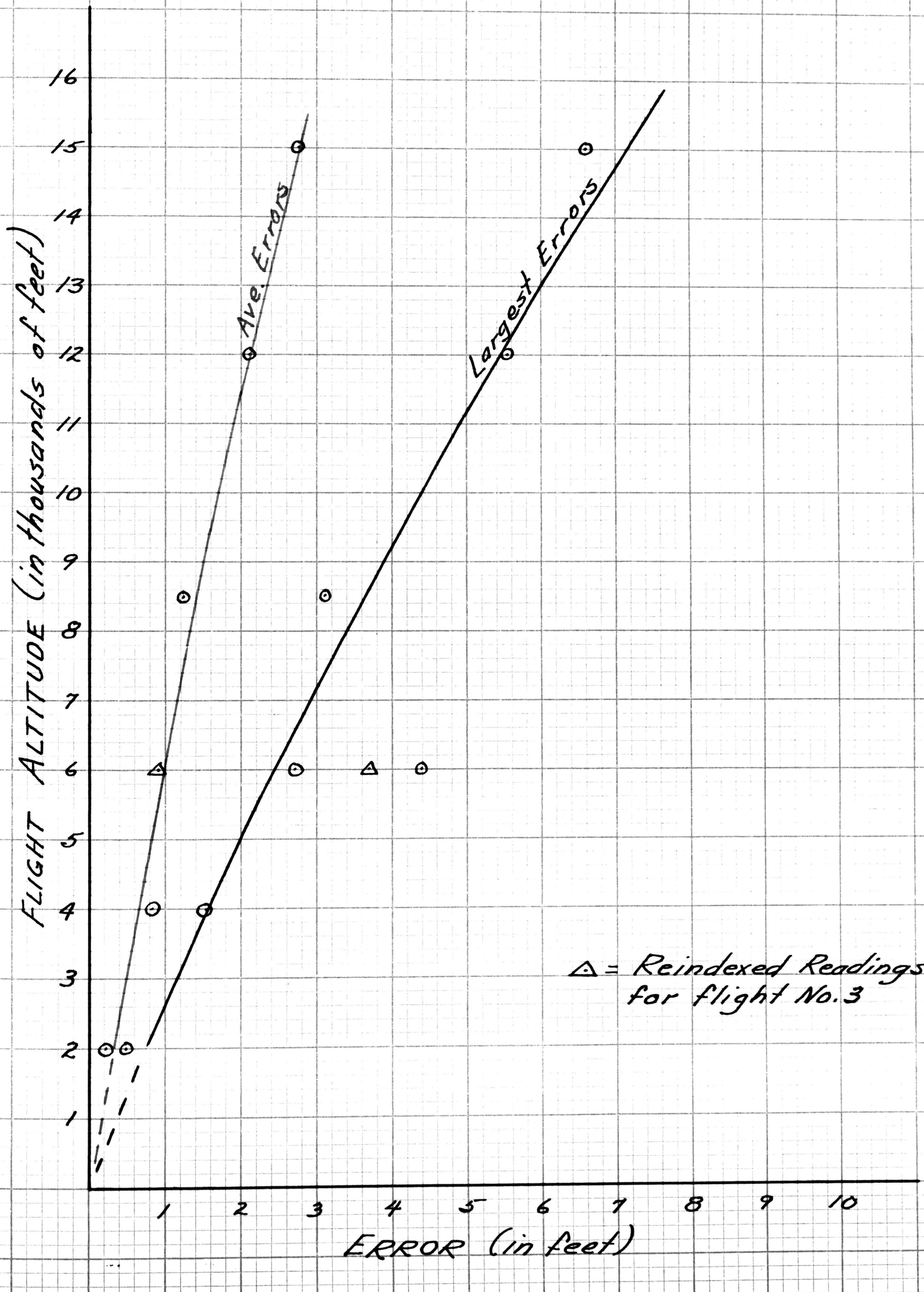
Ave. error = .064mm = 2.08 feet

SPOT READINGS (cont.)

FLIGHT 6

| | | | |
|---|---|---|---|
| (1)(20.44) | (2)(23.05) | (3)(21.15) | (4)(22.43) |
| 20.35 | 22.95 | 21.10 | 22.28 |
| 20.35 | 22.98 | 21.15 | 22.35 |
| 20.35 | 22.95 | 21.12 | 22.35 |
| Ave.=20.35 | Ave.=22.96 | Ave.=21.12 | Ave.=22.33 |
| -.09 | -.09 | -.03 | -.10 |
| (5)(23.89) | (6)(24.17) | (7)(24.21) | (8)(26.03) |
| 23.82 | 24.15 | 24.15 | 26.05 |
| 23.82 | 24.16 | 24.15 | 26.05 |
| 23.85 | 24.08 | 24.15 | 26.12 |
| Ave.=23.83 | Ave.=24.13 | Ave.=24.15 | Ave.=26.07 |
| -.06 | -.04 | -.06 | +.04 |
| (9)(24.35) | (10)(23.83) | (11)(22.55) | (12)(22.72) |
| 24.20 | 23.82 | 22.45 | 22.78 |
| 24.20 | 23.85 | 22.46 | 22.78 |
| 24.18 | 23.85 | 22.46 | 22.78 |
| Ave.=24.19 | Ave.=23.84 | Ave.=22.46 | Ave.=22.78 |
| -.16 | -.01 | -.09 | +.06 |
| (13)(21.31) | | | |
| 21.35 | | | |
| 21.35 | | | |
| 21.35 | | | |
| Ave.=21.35 | | | |
| +.04 | | | |

Maximum error = .16 = 6.61 feet
Ave. error = .067mm = 2.77 feet




SPOT READING ACCURACY CURVE

## DRAWING CONTOURS AND TRANSFERRING POINTS

The test contours were drawn on tracing paper instead of on the base sheet. A piece of 9H lead sharpened to a fine point was used in the tracing table and adjusted for light contact with the paper. This resulted in a fine line or groove being cut slightly into the paper which was only faintly visible to the naked eye, but clearly to be seen with a reading glass.

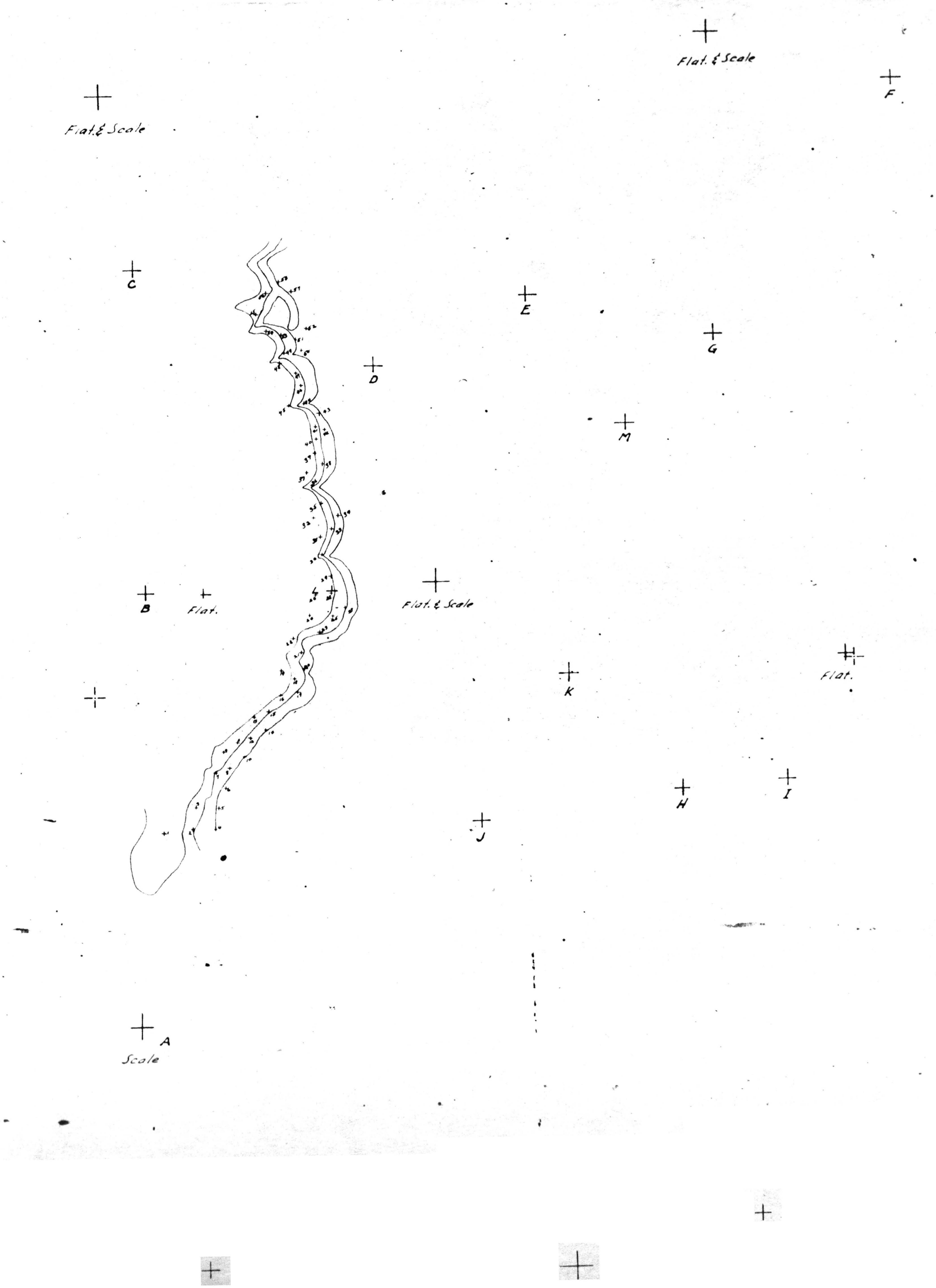
After the contours were traced by the operator, the position of each marker was carefully projectedonto the tracing paper, also. For this purpose a small steel point was used in the tracing table instead of a piece of lead. The result was a faintly pricked hole that also was visible only under magnification.

The contours were inked and small open-center crosses placed to indicate the position of the points in order to obtain prints. Also, the photo center and points used for scaling, flattening and spot reading are shown to illustrate the distribution pattern. (Figure 9).

## MEASURING H DISTANCES

After the contours were traced and the marker positions were pricked, the tracing was magnified approximately three times and horizontal measurements were made from each point to the nearest point on the contour being checked, except in the case of points located in a valley or draw. In this case the distance to the contour was measured up or down the valley. A

Figure 9. Sample of Test Contours. Lettered Points Represent Spot Reading Positions.



scale graduated in hundreths of an inch was used for this measurement. Under magnification this afforded an estimation to a thousandth of an inch. The results of these measurements were recorded on a field check form. (Figure 10) Twenty-four pages of these were checked.

Two sets of contours were traced at each altitude. One set was very carefully and slowly traced while the other was traced at normal operating speed. The very careful method being seldom used in practice is, therefore, considered to be of little significance and is omitted in the writing of this thesis. Suffice it to say that the results produced similar curves, though the V.C. curve was somewhat steeper than the other.

## FIELD CHECKING THE RESULTS

The equipment used consisted of a dumpy level, a Philadelphia rod, a 100 foot chain and a clip board to hold the check sheets.

The checking party consisted of an instrument man (who also acted as recorder), a chain man and a rodman.

Since a fifteen percent slope causes an error of only slightly more than one percent when measured along the slope instead of horizontally, it was not considered necessary to use a second chainman in order to plumb the chain in measuring the H-distances except under unusual circumstances. Such unusual circumstances consisting mainly of points that required measurements of more than fifty feet and where obstacles were

Figure 10
Sample Field Check Sheet

| POINT ELEV. | FLT. NO. | CONT. ELEV. | H.I. | SPEED | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | VERY CAREFUL | | | | NORMAL OPERATING | | | | |
| | | | | H.DIST fr.pt. | Rod Read | Gr.El. Cont. | Err. (ft) | H.DIST fr.pt. | Rod Read | Gr.El. Cont. | Err. (ft) | |
| 944.8 | 4 | 948.8 | 948.9 | +.04<br>+ 24 | 1.7 | 947.2 | +1.6 | +.054<br>+ 33 | 1.0 | 947.9 | +0.9 | |
| | 5 | 948.0 | | -.019<br>- 16 | 5.8 | 943.1 | +4.9 | 0<br>0 | | 944.8 | +3.2 | |
| | 6 | 945.0 | | +.045<br>+ 47 | -0.5 | 949.4 | -4.4 | 0<br>0 | | 944.8 | +0.2 | |
| | 7 | 945.0 | | | | | | | | | | |
| | | | | | | | | | | | | |
| 937.8 | 1 | 940.8 | 943.1 | +.09<br>+ 13 | 3.7 | 939.4 | +1.4 | +.08<br>+ 11 | 4.1 | 939.0 | +1.8 | 937.8<br>5.3 |
| | 2 | 939.0 | | +.008<br>+ 2 | 5.1 | 938.0 | +1.0 | -.021<br>- 6 | 5.7 | 937.4 | +1.6 | 943.1 |
| | 3 | 939.0 | | 0<br>0 | | 937.8 | +1.2 | 0<br>0 | | 937.8 | +1.2 | |
| | 4 | 936.8 | | -.05<br>- 31 | 8.1 | 935.0 | +1.8 | -.032<br>- 20 | 7.3 | 935.8 | +1.0 | |
| | | 942.8 | | +.06<br>+ 37 | 1.8 | 941.3 | +1.5 | +.045<br>+ 27 | 2.6 | 940.5 | +2.3 | |
| | 5 | 938.0 | | -.052<br>- 43 | 8.7 | 934.4 | +3.6 | -.037<br>- 31 | 8.1 | 935.0 | +3.0 | |
| | | | | | | | | | | | | |
| 942.8 | 1 | 940.8 | 948.9 | -.30<br>- 42 | 9.6 | 939.3 | +1.5 | -.26<br>- 36 | 9.3 | 939.6 | +1.2 | 6.1<br>942.8 |
| | | 942.8 | | -.11<br>- 15 | 7.6 | 941.3 | +1.5 | -.07<br>- 10 | 7.1 | 941.8 | +1.0 | 948.9 |
| | | 944.8 | | +.06<br>+ 8 | 5.6 | 943.3 | +1.5 | +.07<br>+ 10 | 5.4 | 943.5 | +1.3 | |
| | 2 | 939.0 | | -.148<br>- 44 | 9.9 | 939.0 | 0 | | | | [illegible] | |
| | | 943.0 | | -.053<br>- 16 | 7.6 | 941.3 | +1.7 | -.081<br>- 24 | 8.2 | 940.7 | +2.3 | |
| | | 947.0 | | +.140<br>+ 42 | 2.3 | 946.6 | +0.4 | +.075<br>+ 23 | 4.0 | 944.9 | +2.1 | |
| | 3 | 939.0 | | -.11<br>- 47 | 10.0 | 938.9 | +0.1 | -.12<br>- 52 | 10.5 | 938.4 | +0.6 | |
| | | 944.0 | | 0<br>0 | [illegible] | 942.8 | +1.2 | -.025<br>- 11 | 7.2 | 941.7 | +2.3 | |
| | 4 | 942.8 | | -.01<br>- 6 | 6.7 | 942.2 | +0.6 | -.01<br>- 6 | 6.7 | 942.2 | +0.6 | |
| | 5 | 938.0 | | -.096<br>- 80 | 12.7 | 936.2 | +1.8 | -.064<br>- 53 | 10.6 | 938.3 | -0.3 | |
| | | 948.0 | | +.014<br>+ 12 | 5.0 | 943.9 | +4.1 | +.015<br>+ 13 | 4.9 | 944.0 | +4.0 | |
| | 6 | 945.0 | | +.070<br>+ 74 | -0.8 | 949.7 | -4.7 | +.020<br>+ 21 | 4.2 | 944.7 | +0.3 | |
| | 7 | 945.0 | | | | | | | | | | |
| | | | | | | | | | | | | |

encountered. Otherwise, the end of the chain was fixed to the center of the flight marker by means of a chaining pin and the chain then pulled straight up or down the slope and the H-distances measured off.

A stake had been placed as the center of each marker when the original survey was made. This afforded a means of contimually checking the H. I. by reading from marker to marker. Likewise, it was a check on the elevation of the markers. No errors were found.

The elevation of the ground at the plotted position of the contour was determined simply by measuring off the carefully scaled H-distances, taking a rod reading and subtracting it from the H.I.

After the ground elevation of the contour positions were determined, the errors were determined by subtracting the ground elevation from the contour elevation or vice versa. A plus (+) sign was used to indicate that the contour was floating, while a minus (-) sign was used to indicate that the contour was in the ground. In the final evaluation of the errors and plotting the curves, however, the sign of the error was not considered.

A tabulation of the resultant errors and a curve of the errors versus flight altitude follows. (Figures 11 and 12)

FINAL RESULTS

VERTICAL ERROR (In feet)

| Point No. | Flight No. 1 | Flight No. 2 | Flight No. 3 | Flight No. 4 | Flight No. 5 | Flight No. 6 |
|---|---|---|---|---|---|---|
| 1 | -1.1 | -0.8 | -0.6 | -1.3 | +2.9 | -4.4 |
| 2 | +0.5 | +0.2 | +1.2 | -0.3 | +3.1 | -3.6 |
| 3 | +0.4 | -1.1 | -0.4 | -1.9 | +2.4 | -1.3 |
| | -- | +1.0 | -- | -0.9 | -- | -- |
| 4 | -- | +1.2 | +1.2 | 0 | +1.5 | -- |
| 5 | -- | +1.1 | +0.4 | 0 | +3.8 | -- |
| 6 | -- | +1.0 | +1.0 | +3.0 | +6.8 | -- |
| 7 | +1.3 | +0.1 | -0.2 | -- | +4.9 | -- |
| 8 | -- | +1.7 | -- | +1.0 | -- | -- |
| 8 | +1.0 | -0.2 | -0.8 | +2.6 | +4.6 | -- |
| | -- | +1.6 | -- | +1.5 | -- | -- |
| 9 | +0.5 | +0.6 | +0.6 | +0.1 | +3.2 | -1.8 |
| | +0.7 | +1.5 | -- | -- | -- | -- |

FINAL RESULTS (cont.)

VERTICAL ERROR (In feet)

| Point No. | Flight No. 1 | Flight No. 2 | Flight No. 3 | Flight No. 4 | Flight No. 5 | Flight No. 6 |
|---|---|---|---|---|---|---|
| 10 | +1.7 | +0.3 | -1.1 | +2.5 | +3.7 | -- |
| 11 | +1.5 | -- | -0.6 | +0.5 | +2.9 | +1.7 |
| | +1.2 | +1.5 | +1.4 | -- | -- | -- |
| | +1.2 | +1.3 | -- | -- | -- | -- |
| 12 | +1.8 | +1.1 | -0.8 | +1.5 | +3.8 | +0.6 |
| | +1.6 | +2.6 | -- | +1.4 | -- | -- |
| 13 | +1.5 | -- | +1.0 | +2.0 | +3.2 | +0.2 |
| | +1.3 | +2.2 | +1.8 | +0.9 | -- | -- |
| 14 | +1.8 | +1.6 | +1.2 | +1.0 | -- | -- |
| | -- | -- | -- | +2.3 | -- | -- |
| 15 | +1.2 | -- | +0.6 | +0.6 | -0.3 | +0.3 |
| | +1.0 | +2.3 | +2.3 | -- | +4.0 | -- |
| | +1.3 | +2.1 | -- | -- | -- | -- |
| 16 | +2.2 | +1.8 | -0.6 | -0.1 | +3.2 | -2.6 |
| | -- | +1.2 | 0.0 | -0.2 | -- | -- |

FINAL RESULTS (cont.)

VERTICAL ERROR (In feet)

* = in woods

| Point No. | Flight No. 1 | Flight No. 2 | Flight No. 3 | Flight No. 4 | Flight No. 5 | Flight No. 6 |
|---|---|---|---|---|---|---|
| * 17 | +1.5 | +0.6 | -0.8 | -1.2 | +4.7 | -- |
| | +2.0 | +1.2 | -0.2 | -- | -- | -- |
| * 18 | +0.9 | -- | -0.4 | -0.7 | +1.8 | -3.3 |
| | +0.4 | -- | -1.1 | -0.1 | -- | -- |
| * 19 | -- | +0.8 | -1.4 | -0.6 | -- | -2.9 |
| * 20 | +0.3 | -0.6 | -1.8 | +0.9 | +2.6 | -- |
| | +0.1 | +0.4 | -1.0 | -2.5 | -- | -- |
| * 21 | +1.5 | 0.0 | -0.8 | -- | -- | -- |
| | -- | -- | -- | -- | -- | -- |
| * 22 | +0.5 | +0.1 | -0.8 | -0.1 | +1.6 | -2.8 |
| * 23 | +1.8 | -- | -0.4 | +2.1 | +2.8 | -- |
| | +1.4 | +2.4 | -1.5 | -- | -- | -- |
| | +1.2 | -- | -- | -- | -- | -- |
| 24 | -- | -- | -1.3 | -0.7 | +0.4 | -5.8 |

FINAL RESULTS (cont.)

VERTICAL ERROR (In feet)

* = in woods

| Point No. | Flight No. 1 | Flight No. 2 | Flight No. 3 | Flight No. 4 | Flight No. 5 | Flight No. 6 |
|---|---|---|---|---|---|---|
| *25 | +1.5 | +2.0 | -0.5 | +1.5 | +0.1 | -- |
| | -- | +1.2 | -1.6 | +0.5 | -- | -- |
| 26 | -- | -- | -1.4 | +1.6 | -- | -6.2 |
| *27 | +1.4 | +0.8 | -1.8 | +0.7 | +2.2 | -- |
| | +1.8 | +1.3 | -1.2 | -- | -- | -- |
| | +1.2 | +1.5 | -- | -- | -- | -- |
| 28 | +0.3 | +0.6 | -2.0 | +1.5 | +0.4 | -7.6 |
| 29 | +0.4 | -0.6 | -1.8 | -1.1 | +1.6 | -4.8 |
| | -- | +1.1 | -2.2 | +1.8 | -- | -- |
| *30 | +1.3 | -0.3 | -1.0 | -1.8 | +1.0 | -4.3 |
| | +0.6 | -- | -- | -- | +1.4 | -- |
| 31 | +0.4 | +1.2 | -0.9 | -0.3 | +0.2 | -3.4 |
| 32 | -- | +2.2 | -1.3 | +1.6 | +2.7 | -1.2 |

FINAL RESULTS (cont.)

VERTICAL ERROR (In feet)

| Point No. | Flight No. 1 | Flight No. 2 | Flight No. 3 | Flight No. 4 | Flight No. 5 | Flight No. 6 |
|---|---|---|---|---|---|---|
| 33 | +1.1 | +1.3 | -1.1 | +0.7 | +1.8 | -3.1 |
| | +1.4 | +1.7 | -1.9 | -- | -- | -- |
| | +1.1 | -- | -- | -- | -- | -- |
| 34 | +1.6 | +1.1 | -1.0 | +2.8 | +5.1 | -- |
| | -- | -- | -- | +1.9 | -- | -- |
| 35 | +0.6 | 0.0 | -2.1 | +0.6 | +2.1 | -2.3 |
| | +1.0 | +1.4 | -1.7 | +2.1 | -- | -- |
| 36 | -0.7 | +1.4 | -2.2 | 0.0 | +4.1 | +2.2 |
| | 0.0 | +0.2 | -3.0 | -- | -- | -- |
| | +0.8 | -- | -- | -- | -- | -- |
| 37 | -- | +2.1 | -1.5 | -1.0 | +4.4 | +1.6 |
| 38 | +1.1 | +0.9 | -0.3 | +1.9 | +5.2 | -- |
| | +0.7 | +2.1 | -2.0 | -- | -- | -- |
| | +0.4 | +1.7 | -- | -- | -- | +2.2 |

FINAL RESULTS (Cont.)

VERTICAL ERROR (In feet)

| Point No. | Flight No. 1 | Flight No. 2 | Flight No. 3 | Flight No. 4 | Flight No. 5 | Flight No. 6 |
|---|---|---|---|---|---|---|
| 39 | +0.2 | +1.5 | -0.7 | -0.6 | +3.3 | +3.4 |
| | -- | -- | -2.5 | -- | -- | -- |
| 40 | +0.5 | +0.7 | -0.8 | +0.9 | +2.9 | +3.7 |
| | +0.1 | +1.4 | -- | -0.5 | -- | -- |
| 41 | -0.3 | +1.4 | -1.9 | +0.8 | +4.5 | +1.5 |
| | +0.4 | -- | -0.1 | -- | -- | -- |
| | -1.1 | -- | -- | -- | -- | -- |
| 42 | +1.7 | +1.1 | -1.6 | +1.3 | +2.6 | -- |
| | -- | -- | -- | +0.9 | -- | -- |
| 43 | +0.6 | +0.2 | -1.2 | -1.3 | +1.6 | -- |
| 44 | 0.0 | -0.1 | -1.8 | -0.6 | +3.6 | -- |
| | +0.5 | -0.1 | -1.5 | -- | -- | -- |
| 45 | -0.3 | -0.5 | -1.8 | -2.8 | -- | -2.3 |
| 46 | -0.1 | +2.1 | -0.3 | -0.5 | +1.1 | +0.7 |

FINAL RESULTS (cont.)

VERTICAL ERROR (In feet)

| Point No. | Flight No. 1 | Flight No. 2 | Flight No. 3 | Flight No. 4 | Flight No. 5 | Flight No. 6 |
|---|---|---|---|---|---|---|
| | +0.5 | -- | -- | -- | -- | -- |
| | +0.1 | -- | -- | -- | -- | -- |
| 47 | +0.2 | +1.7 | +0.2 | -2.0 | +1.0 | +1.0 |
| | 0.0 | -- | -- | -- | -- | -- |
| 48 | +0.6 | -2.8 | -- | -1.0 | +2.4 | -0.6 |
| | -- | -2.5 | -- | -- | -- | -- |
| 49 | -0.1 | +0.1 | -1.1 | -1.9 | +1.1 | -1.6 |
| | +0.1 | +0.2 | -1.2 | -- | -- | -- |
| | +0.1 | +0.5 | -- | -- | -- | -- |
| 50 | -- | -0.4 | -1.5 | -1.9 | +2.2 | -- |
| 51 | +0.3 | +0.2 | -2.2 | -2.7 | +0.8 | -- |
| | -- | +1.0 | -1.6 | -0.9 | -- | -- |
| 52 | -- | -- | -- | -3.0 | -- | -- |
| 53 | +0.1 | -0.7 | -2.6 | -0.9 | -1.0 | -0.7 |
| | +0.5 | +0.9 | -1.3 | -- | +2.4 | -- |

FINAL RESULTS (cont.)

VERTICAL ERROR (In feet)

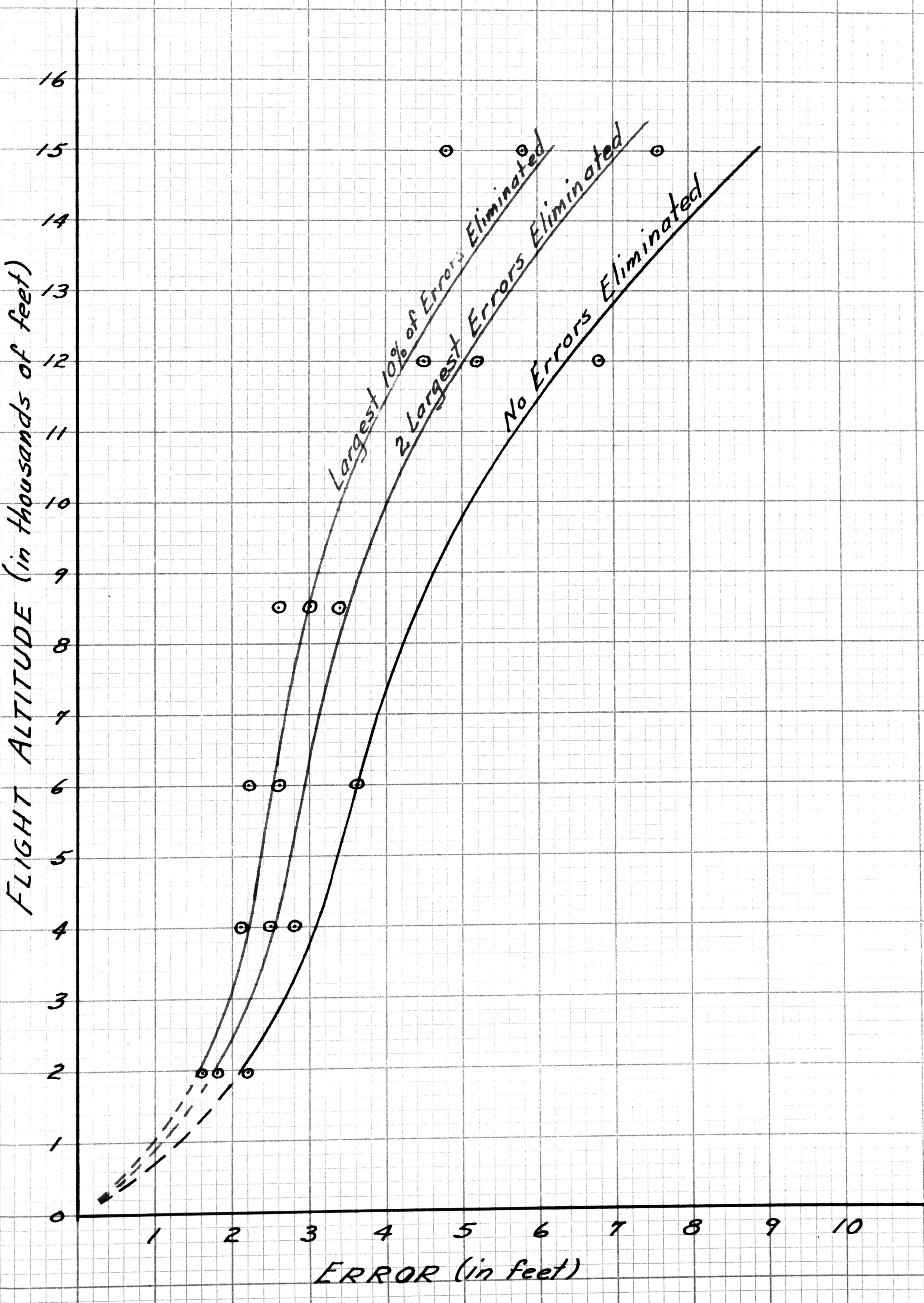
* = in woods

| Point No. | Flight No. 1 | Flight No. 2 | Flight No. 3 | Flight No. 4 | Flight No. 5 | Flight No. 6 |
|---|---|---|---|---|---|---|
| | +0.5 | +1.1 | -- | -- | -- | -- |
| 54 | -1.3 | -0.2 | -2.0 | -2.0 | +1.9 | +0.6 |
| | +0.4 | +0.1 | -1.3 | +1.9 | -- | -- |
| *55 | +0.7 | +0.2 | -2.5 | -- | -- | -- |
| | +0.4 | -- | -1.5 | -- | -- | -- |
| | +1.4 | -- | -- | -- | -- | -- |
| 56 | -0.1 | -2.2 | -0.3 | -3.4 | +2.4 | -1.3 |
| | +0.3 | -0.9 | -1.4 | -2.1 | -- | -- |
| 57 | -- | -- | -- | +3.0 | +0.2 | -- |
| 58 | 0.0 | +0.8 | +0.6 | +2.4 | +6.1 | -- |
| | -- | -- | -- | 0.0 | -- | -- |
| 59 | 0.0 | -0.4 | -2.2 | +0.4 | +5.5 | -2.1 |
| | +0.7 | +1.2 | -3.6 | -1.1 | -- | -- |
| | +0.3 | +1.4 | -- | -0.3 | -- | -- |

FINAL RESULTS (cont.)

VERTICAL ERROR (In feet)

| Point No. | Flight No. 1 | Flight No. 2 | Flight No. 3 | Flight No. 4 | Flight No. 5 | Flight No. 6 |
|---|---|---|---|---|---|---|
| 60 | -- | -0.9 | +1.0 | +0.2 | +2.2 | -- |
| Summation -- | 73+'s<br>9-'s | 65+'s<br>19-'s | 14+'s<br>67-'s | 38+'s<br>36-'s | 53+'s<br>3-'s | 13+'s<br>23-'s |




CONTOUR ACCURACY CURVE

## CONCLUSIONS

General Discussion of the Results. The group of errors determined appears to be very representative of actual mapping practice. Although the shape of the lower portion of the accuracy curves came as somewhat of a surprise, there are some good arguments as to why it should be so, as will be pointed out later. It is significant that the shape of all three curves plotted are very similar. If the shape had changed radically after some of the largest readings were discarded, it would have been taken as indicative of unreliable results.

It is evident from an examination of the errors that the progression is uniform from zero to a maximum. There is no sudden leap to a larger positive or negative value in any of the altitudes as the readings near their top values. In fact, an examination of the curves shows that the variation in the top ten percent of the errors for each altitude is remarkably uniform.

Significance is placed upon the fact that in flights 1, 2, 3, 5, and 6, the errors are overwhelmingly positive or overwhelmingly negative. This, no doubt, is due primarily to the orientation solution.

Flight number 4 yielded the best group of readings with 38 positive and 36 negative errors. While this is, of course, a highly desirable condition, it is felt that since this represents a better orientation solution than is generally achieved in practice, it should not be allowed to influence the accuracy curve too much. This represents an unbiased group of precise measurements.(1)

(1) Eisenhart, Churchill and Bicking, C.A., The Reliability of Measured Values, Photogrammetric Engineer, Vol.18, pp.543-558, June 1952

The spot readings produce a good curve if the readings for altitude number 3 are omitted. The large error in this group of readings cannot be accounted for. The model apparently flattened well and no residual or local parallax was noticed. The contours checked well, yielding no outstanding errors as may be seen upon examining the accuracy curve. It is possible that the readings were taken some distance from the true position. In some of these points there is an elevation change close by the point such as a road embankment or the corner of a pasture with weeds and briars growing just beyond reach of the cattle. Another possibility is that the Veeder Root counter may have been set wrong in indexing. If the counter were corrected by +.20 mm, only point number 7 would be slightly above the expected range of error.

The writer, also, took spot readings on the models as a check against the operator. This set of readings indicated nothing out of the ordinary for this particular altitude. These readings yield a maximum error of .10mm which is equivalent to 1.69 feet, and an average error of .042mm or .71 feet. Both the operator's indicated error and his reindexed error are plotted for the reader's con-

convenience in forming his own opinion of the probable cause of this discrepancy.

Discussion of theory. At very low altitudes, leaves on weeds, the blades of tall grasses and like objects tend to retain their identity in a photograph. The motion of the camera helps to cause a confusion of this detail with the earth or background. When coupled with the effects of increased bumpiness, the possible effects of heat waves dancing close to the earth's surface and probably numerous other things, the stereo model has a characteristic softness that tends to disappear with increased altitude. This causes the error curve to change its shape from convex upward at high altitudes to concave upward at low altitudes.

The adverse effects of low flying are not so apparent where the area is closely cropped pasture land or an open area where the ground surface is more or less level and well defined. The points used for spot readings fell principally in areas of such good negative definition, thus accounting for the apparent incompatibility of the accuracy curve and the spot reading curve near the lower extremities.

## SUMMARY

Greatest economy in mapping is achieved when the flight height is the maximum consistent with the required accuracy of the finished compilation. The curves presented in this study can be of considerable value in establishing a means of determining what the most economical flight height (or "C" factor) should be for any prescribed accuracy.

Different conditions of topography, cover, geology and cultivation have an effect on the accuracy of a map, thus requiring additional curves to cover all the conditions that might be encountered throughout the United States. However, one or two additional curves could be made to cover the whole realm of conditions adequately.

The spot reading curve represents that degree of proficiency toward which we should strive.

The accuracy curve with no errors eliminated represents that which is possible today.

# VITA

David Hunter Robinson was born August 5, 1911, in Blackstock, South Carolina, the son of Mr. and Mrs. David W. Robinson. After receiving his elementary education at Blackstock, he entered Clemson College in 1929. His education was temporarily interrupted by the depression of the 1930's. In 1938, he resumed his studies and was graduated in the class of 1941.. Upon graduation he was ordered to active duty as a second lieutenant in the Army. On September 5, 1942, he was married to Miss Marie Osteen of Anderson, S. C.

After serving four and one half years in the Topographic branch of the Corps of Engineers and being awarded the Bronze Star Medal for outstanding performance of duty with Third U.S. Army in the European theatre, he was separated in January, 1946 with the rank of captain. He accepted a position as head of the Control Branch of Operations and Planning Division of the Army Map Service in Washington, D. C.

In February, 1947, he returned to Clemson College as an assistant professor for the purpose of establishing classes in Photogrammetry.

In September 1951, he entered the University of Missouri School of Mines and Metallurgy for work on a master of science degree in civil engineering.